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DAIRY BARN EXHAUST AIR HEAT RECOVERY FOR HOME HEATING UTILIZING A DUAL HEAT PUMP SYSTEM

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ABSTRACT

A dual heat pump system was installed in a dairy barn for exhaust air heat recovery. Heat recovered was used for home heating. Monitoring from December 22, 1985 to March 13, 1986 indicating an average system Coefficient of Performance (COP) of only 1.2, ranging on a daily basis from 0.75 to 1.8. Modifications are required to improve the system COP such as increased fin spacing and orientation to air flow of the barn evaporator coil and an improved heat storage system.

Introduction

The utilization of heat pumps in agriculture is increasing. New technology such as ground and water source heat pumps for space heating have been readily adapted to greenhouses and homes (Spieser, 1982). Air source heat pumps have also been used to recover exhaust air heat from finishing hogs for space heating of farrowing and weaning facilities (Vancleif et al., 1983) and from dairy barn exhaust air for home heating (MacDonald, 1985).

Waste heat recovery from bulk milk tanks for water heating has been proven economic for larger scale dairy operations (Winfield, Gee, 1983) and waste heat from fruit storage and processing can supply some space heating (MacDonald, 1982).

Further testing is also being carried out on the following systems:

. Broiler barn heating using three ground source heat pumps
. Mushroom plant heating and cooling using three ground source and pond water heat pumps
. Home heating with water source heat pump using PVC tubing suspended in a hog finishing barn

This report outlines a dual heat pump system for recovery of dairy barn exhaust for home heating.

Facility Description

An older barn houses about 57 milking Holstein cows at about 600 kg. (See Figure 1 and Figure 2) Heat production from dairy cattle is estimated at 2.2 W/kg at 10° C (Yeck, Stewart, 1959(. For 57 cows, this is 270,000 kJ/h of heat, more than enough to heat most homes at even 20% recovery.

The home has 172 m² of floor area; including a well-insulated 52 m² addition. The home is older with only some insulation in the attic, none in the walls and is generally not very air tight around doors and windows.

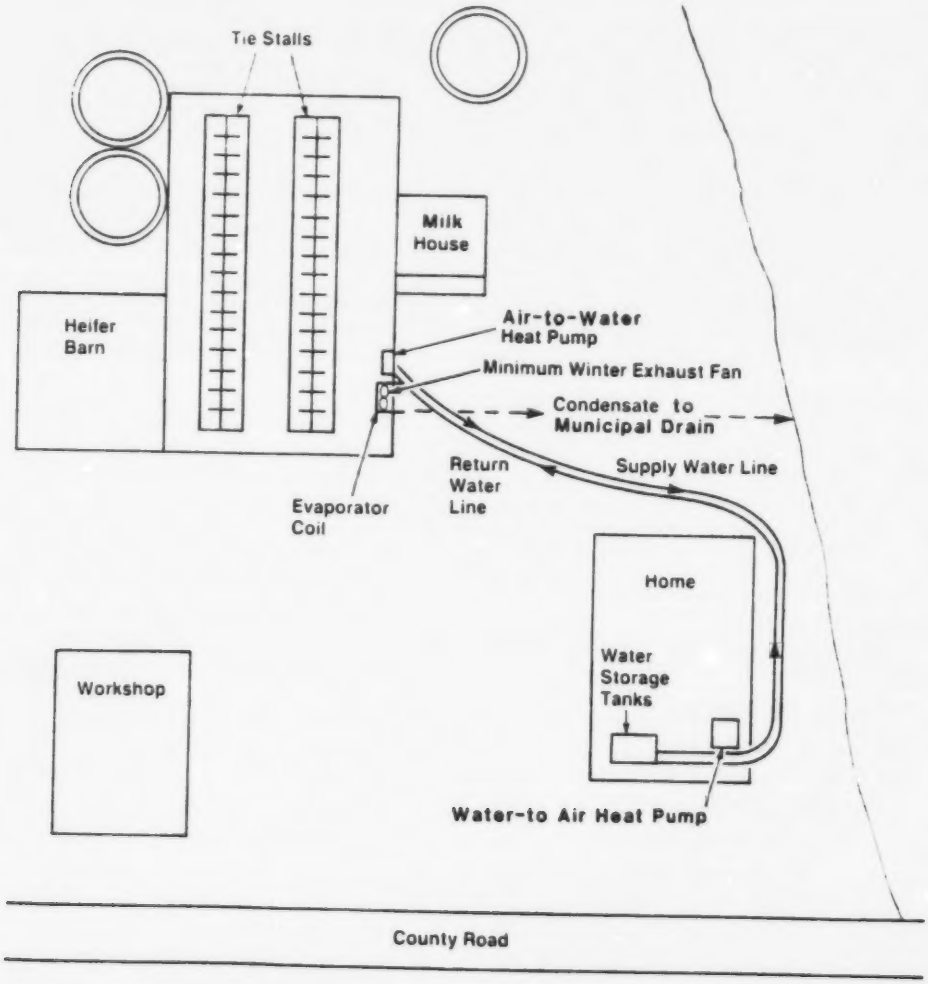


Figure 1. Plan View of Dairy Barn With Dual Heat Pump System

System Design and Operation

The older original home oil furnace had a rated output of 116,000 kJ/h. Based on 60% efficiency and 80% operating times during cold weather, a 57,000 kJ/h (4.5 ton) heat pump was used to supply home heat.

The system can be broken down into two interconnected heat pump systems:

(1) A 3.25 ton air-to-water heat pump in the barn for dairy barn exhaust air heat recovery. (See Figure 6A, B)

(2) A 4.5 ton water-to-air heat pump in the home for forced air home heating. (See Figures 1, 2 and 7A, B)

In order to alleviate potential heating shortages during extreme cold and while the cows are out of the barn on cold mornings, heat back-up and storage was built in (See Figure 3). Figure 4 shows a modified heat storage system which would simplify the system and improve efficiency.

System operation is as follows:

. Dairy barn exhaust air passes through an evaporator coil, located on the suction side of the minimum winter exhaust fan.

. The heat pump uses the recovered heat from the exhaust air to heat water to about 30° C.

. This heated water is pumped underground through a 50 mm pvc tube and into the storage tanks in the basement.

. On demand, the home heat pump draws water from the storage tanks for a heat source to heat air.

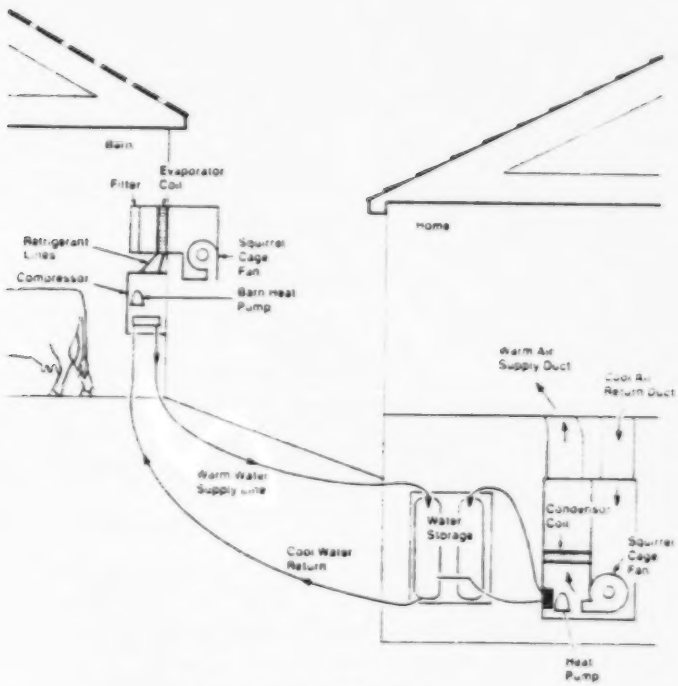


Figure 2. Schematic of Heat Pump System

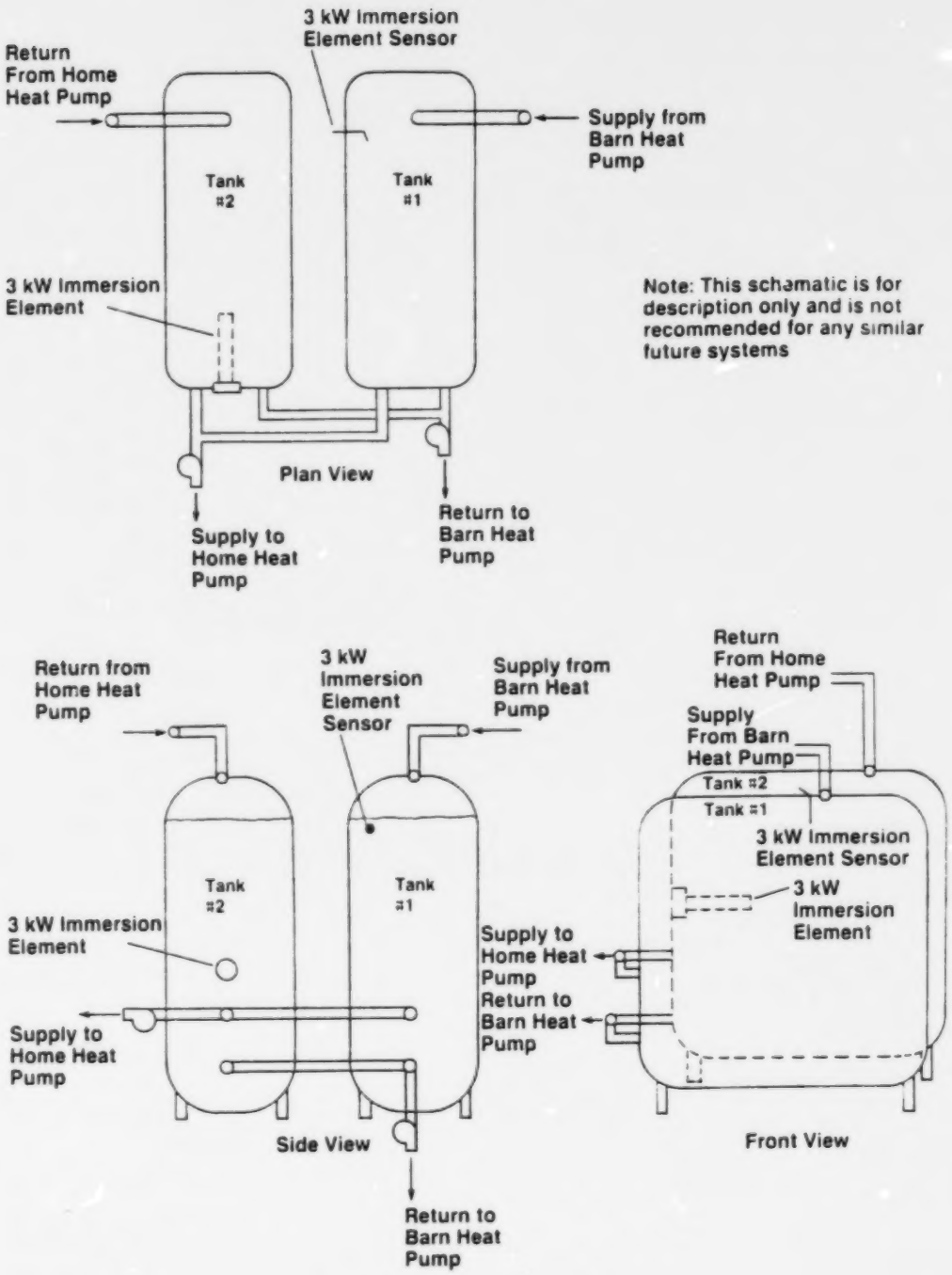

3 kW Immersion Element Sensor
Return From Home Heat Pump
Supply from Barn Heat Pump
Tank #2
Tank #1
3 kW Immersion Element
Note: This schamatic is for description only and is not recommended for any similar future systems
Plan View
Supply to Home Heat Pump
Return to Barn Heat Pump
Return from Home Heat Pump
3 kW Immersion Element Sensor
Supply from Barn Heat Pump
Return From Home Heat Pump
Supply From Barn Heat Pump
Tank #2
Tank #1
3 kW Immersion Element Sensor
3 kW Immersion Element
Supply to Home Heat Pump
Return to Barn Heat Pump
Side View
Front View
Return to Barn Heat Pump

Figure 3. Heat Storage System

The water is continually pumped from the water storage to the barn heat pump. A temperature sensor upstream from the barn heat pump will activate the barn heat pump when water temperature drops below 10.3° C (indicating 10.3° C at the storage tanks) and turn the heat pump off when water temperatures exceed 11.1° C. If water in the storage tanks drops below 9° C, a 3 kW immersion element will activate.

Monitoring

The monitoring system consisted of:

- Hour meters recording running time of both heat pumps and the 3 kW immersion element.
- An energy integrator measuring the heating output of the heat pump in the house.
- Spot checks of current and voltage for both heat pumps. Figures used in calculating energy requirements were 17.5 A (barn), 24 A (home) @ 240 v.

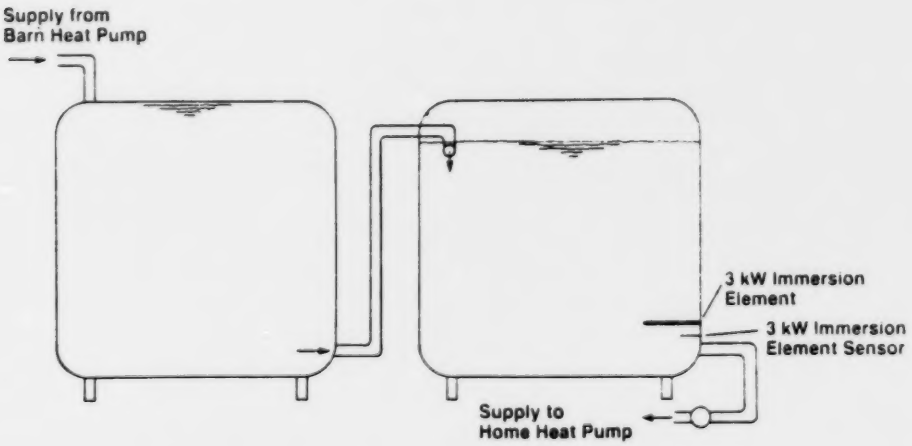


Figure 4. Simplified Schematic of Recommended Heat Storage System.

Results

Calculated energy required for system operation from November 2/85 through May 27/86 was:

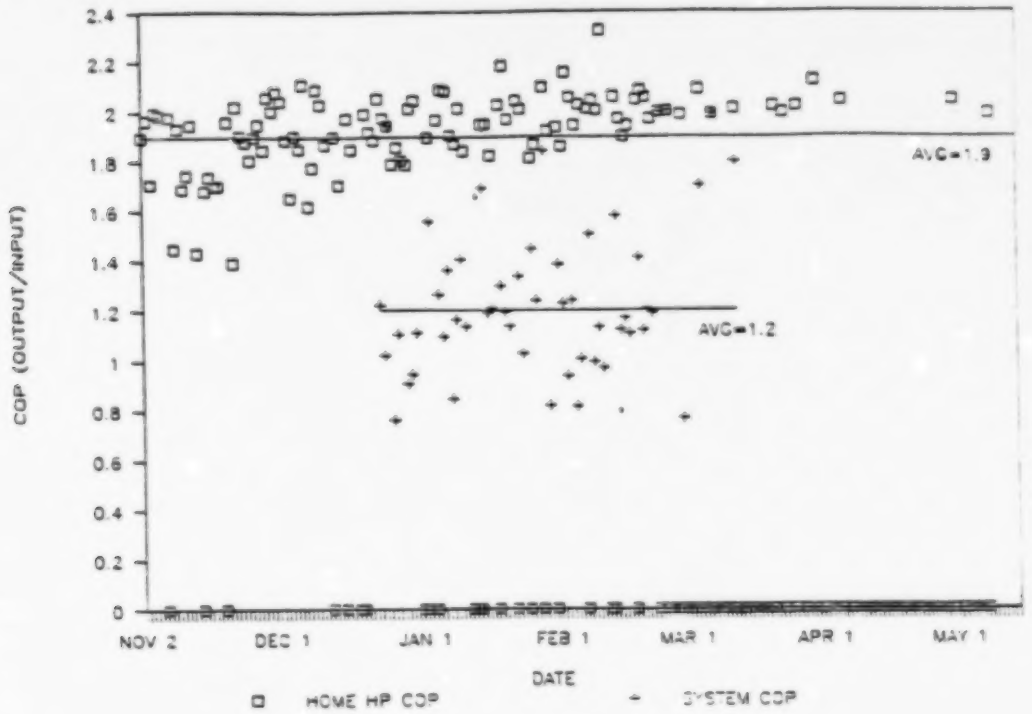
(1) Home heat pump	- 8898 kWh	42.7%
(2) Barn heat pump	- 8442 kWh	40.5%
(3) 3 kWh immersion element	- 3482 kWh	16.8%
TOTAL:	20,822 kWh	

For electricity costs of $0.05/kWh, this system cost $1041 to operate, a 50% saving over estimated oil costs of $2000 from previous years.

Figure 5 shows the COP for the home heat pump itself (Nov. 2/85 - May 14/86) and also the system COP (Dec. 22/85 - March 13/86).

The home heat pump average COP was only 1.9 (based on heat energy output divided by electricity to run the compressor), somewhat lower than the expected 3.0. This can be attributed to several factors such as lower-than-designed-for air flow rates in the house ducting, cooler water storage tank temperatures than required (as evidenced by the large amount of energy used by the 3 kWh immersion element) and dirt accumulation on the electronic filtering system in the furnace ductwork, further reducing air flow rates.

Figure 5: Coefficients of Performance Data



The system COP includes the energy required to operate both heat pumps plus the electric immersion element. This COP, only recorded during coldest weather operation, was 1.2, a very low number. The main problem was due to low water temperature in the storage tanks. Low water temperature was caused by a continuous problem of fouling and frost formation of the evaporator coil recovering heat from the dairy barn exhaust air. Poor heat recovery resulted which caused both heat pumps and the immersion element to operate much longer than expected.

Recommendations

To improve system efficiency, the following changes are required:

. Filter system in the barn requires automation or frequent manual cleaning or an automatic cleaning system installed
. Expanded fin spacing on the evaporator coil, reducing fouling and frost, thus improving efficiency
. Evaporator coil should be tilted 45° into the direction of air flow to facilitate condensate removal, reducing frosting
. Large amounts of air leakage around a nearby door should be reduced to prevent short-circuiting of cold air through the evaporator coil, contributing to lower C.O.P.'s
. The heat storage system requires improvement. Currently, potential exists for the immersion element to be on, heating water which can then be pumped straight to the barn if the home heat pump is not operating (Refer to Figure 3)

A simplified system would consist of all water from the barn pumped into one tank. Overflow would supply the second tank. The immersion element would be located above a supply line to the heat pump and would be operated by a sensor in this supply line. (See Figure 4)

The water would continually be pumped through the home heat pump to the barn, whether either of them was operating or not. However, an interlock to turn off the immersion element when the home heat pump is not running must be installed to eliminate heat wastage.

. Additional heat recovery is possible by pre-warming of water to the home hot water tank using the heat pump. This would be of greatest benefit in the summer when air conditioning is operating and the heat recovered from the home must be dumped anyway.

Conclusions

A dual heat pump system in a dairy barn for home heating had a low COP of 1.2 for cold weather operation. Although heating costs have been substantially reduced, improvements can easily be made to improve system performance, reliability and efficiency.

There are also more efficient methods of heat recovery in livestock facilities utilizing heat pump technology. These would include the use of pvc tubing rather than refrigerant heat recovery in the barn, water and ground source heat pumps and direct refrigerant piped underground as required.

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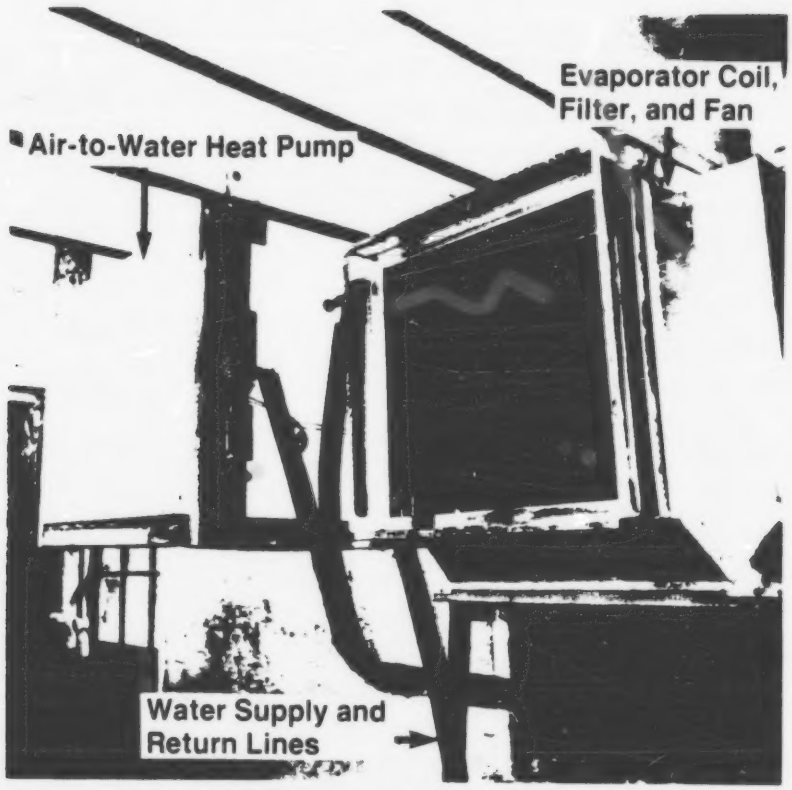

Figure 6A. Barn Heat Pump System

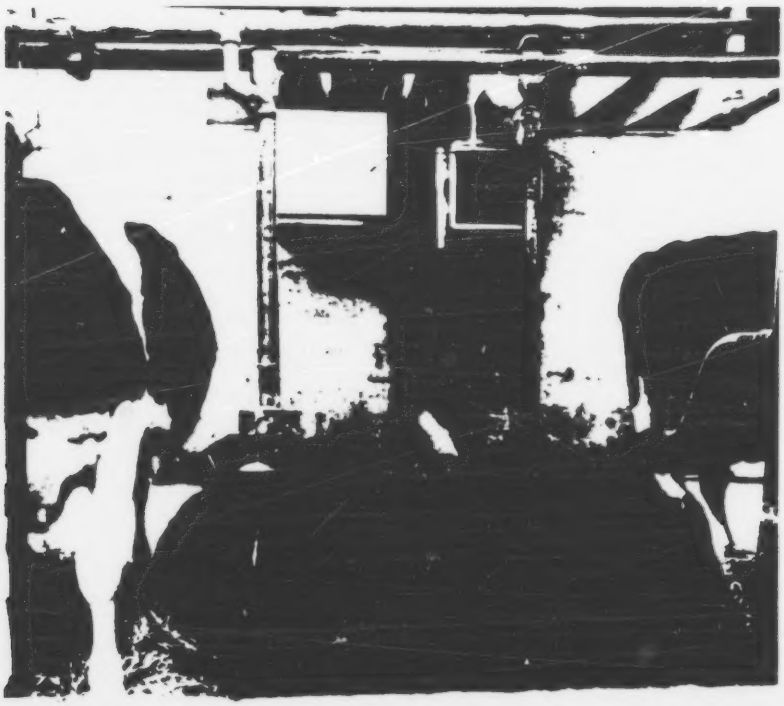

Figure 6B. Barn Heat Pump System

Note that it does not interfere with daily operations, headroom, etc.

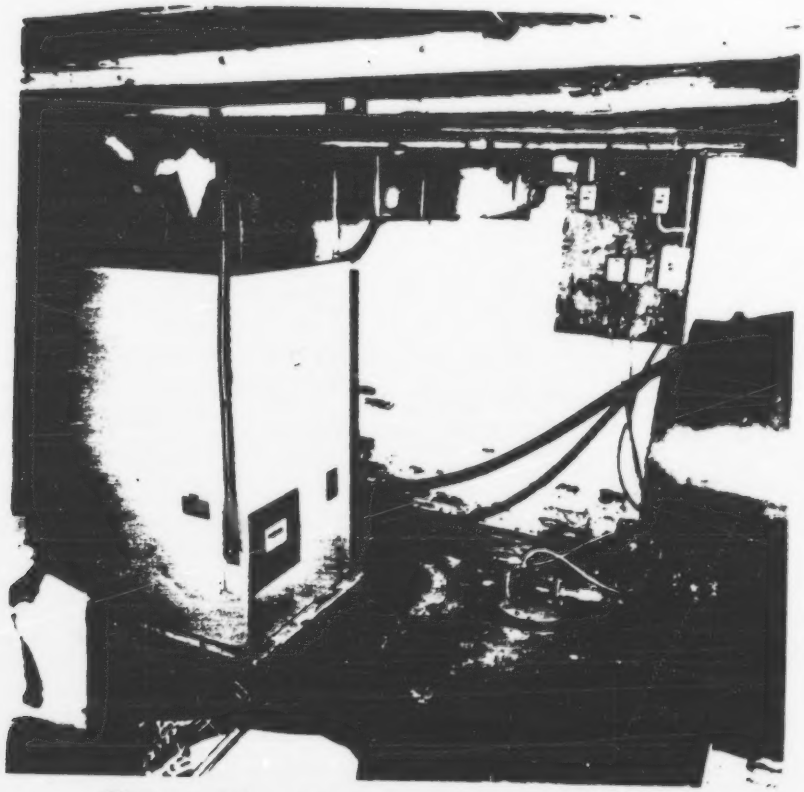

Figure 7A. Home Heat Pump System
With Water Storage

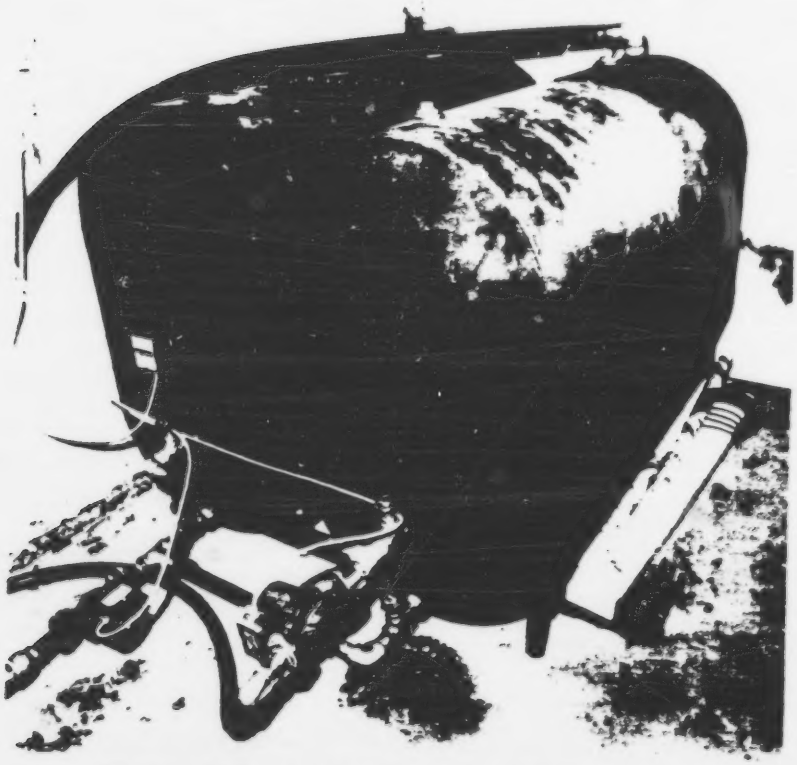

Figure 7B. Water Storage System